AVAILABILITY AND RELIABILITY RESULTS OF CALCULATION FOR HIGH VOLTAGE SWITCHING STATION

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Abstract – The paper gives numerical and graphical results of the calculation for a typical high voltage switchyard. It defines the main model elements which have been used for reliability calculation, reliability parameters as well as fault tree formation. Different possibilities of analysis are shown, i.e. minimum cross-section analysis, analysis of uncertainty, analysis of importance and sensitivity and time dependent analysis.

Keywords: fault tree, reliability, availability, Risk Spectrum.

1. INTRODUCTION

High voltage switching station reliability and availability calculation will be analyzed by means of Risk Spectrum programme package. Therefore, the paper will present the programme package as well as its models and parameters.

2. DEFINITIONS AND TERMINOLOGY OF THE MODEL

2.1. Basic event reliability models

If any quantitative analysis is to be made of a fault tree, a reliability model must be associated with each basic event in the tree. A reliability model is a set of mathematical formulas that specify how to calculate the reliability characteristics of a basic event. The following reliability characteristics are calculated for basic events in Risk Spectrum:

• Unavailability at time t, Q(t)
• Probability or long-term steady-state average unavailability, Q
• Unconditional failure intensity at time t, W(t)

Each reliability model has one or more parameters that appear in the formulas. The formulas used in Risk Spectrum are presented for each reliability model in the following sections. The notation used in the formulas is given below, including the relation to the parameters that are given as input to Risk Spectrum.

All models have one or more required parameters. Several of the reliability models in Risk Spectrum are flexible and cover slightly different modelling situations. These models contain one or more optional parameters in addition to the required ones.

<table>
<thead>
<tr>
<th>Formula parameter</th>
<th>Description</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>q</td>
<td>Prob. demand</td>
<td>q</td>
</tr>
<tr>
<td>λ</td>
<td>Failure rate</td>
<td>r</td>
</tr>
<tr>
<td>f</td>
<td>Frequency</td>
<td>f</td>
</tr>
<tr>
<td>μ</td>
<td>Repair rate</td>
<td>1/τ</td>
</tr>
<tr>
<td>TR</td>
<td>Repair time (MTTR)</td>
<td>TR</td>
</tr>
<tr>
<td>Tl</td>
<td>Test interval</td>
<td>Tl</td>
</tr>
<tr>
<td>TF</td>
<td>Time to first test</td>
<td>TF</td>
</tr>
<tr>
<td>TM</td>
<td>Mission time</td>
<td>TM</td>
</tr>
</tbody>
</table>

Table I. – Parameters used in Risk Spectrum models

2.2. Monitored, Repairable Component (Type 1)

This is a “normal” repairable component. The model assumes exponential distributions both for the failure process and for the repair process, i.e. both the failure rate and the repair rate are constant.

The unavailability Q(t) of this type of component is modelled by:

\[
Q(t) = q e^{(-λ+μ)t} + \left(1 - e^{(-λ+μ)t}\right) / (λ - μ)
\]

(1)

Required parameters: λ, μ (r, TR)
Optional parameters: q

2.3. Periodically Tested Component (Type 2)

This is the most complex of the reliability models in Risk Spectrum. In its simplest form, with only the failure rate and the test interval specified, it corresponds to a “traditional” model for a periodically tested component. It has the following set of required and optional parameters:

Required parameters: λ, Tl (r, Tl)
Optional parameters: q, TR, TF

In this case, unavailability is given by:

\[
Q(t) = 1 - e^{(-λ)(Tl)} \quad Tl = 0, Tl, 2Tl, \ldots
\]

(2)

2.4. Constant Unavailability (Type 3)

This is a simple, but often used, model which uses a constant unavailability q as its only parameter. It is
most commonly used in situations where a "failure probability per demand" is needed. Typically, it is used when modeling components/systems that are activated and change state. Examples: Valves that fail to open/close, circuit breakers that fail to open close, motors that fail to start/stop.

This type of model has no time-dependent behavior. The formulas for unavailability \( Q(t) \), the long-term average unavailability \( Q_{\text{long}} \), and the unconditional failure intensity \( W(t) \) are:

\[
Q(t) = q ; \quad Q = q ; \quad W(t) = 0 ,
\]

(3)

### 2.5. Component with Fixed Mission Time (Type 4)

This is a model which behaves exactly as a type 3 constant unavailability model. In this model, however, the constant unavailability is not given directly as input, it is calculated from a failure rate and a fixed mission time. An optional constant unavailability \( q \) can be added as well.

\[
Q(t) = q + 1 - e^{-\lambda TM} \quad (= \text{constant})
\]

(4)

\[
Q = q + 1 - e^{-\lambda TM} \quad (= \text{constant})
\]

(5)

\[
W(t) = 0
\]

(6)

Required parameters: \( \lambda (t) \), TM

Optional parameters: \( q \)

### 2.6. Constant Frequency (Type 5)

This model is used when an event is best described by a Poisson process, i.e. the events occur with a constant frequency (rate).

\[
Q(t) = 0
\]

(7)

\[
Q = 0
\]

(8)

\[
W(t) = f
\]

(9)

This model should normally be used only for initiating events. Such initiating events are normally used in event trees, but they can also be used as basic events in fault trees. If they are used in fault trees, specific rules need to be followed. This is explained in the description of "frequency type of analysis" in the section about MCS-analysis.

### 2.7. Non-Repairable Component (Type 6)

This is the "traditional" non-repairable component model with an exponential failure model, i.e. a constant failure rate. As with many of the other component models in Risk Spectrum, we have added the possibility of using an optional constant unavailability. This can be used in situations where there is a failure probability per demand at time \( t = 0 \). This model requires a mission time \( T \), which is the time point supplied in the MCS-analysis specification.

\[
Q(t) = q + 1 - e^{-\lambda t}
\]

(10)

\[
W(t) = \lambda (1 - Q(t))
\]

(11)

Required parameters: \( \lambda (t) \)

Optional parameters: \( q \)

For this model it does not make sense to define a long-term steady-state average unavailability \( Q \), because the unavailability increases asymptotically towards 1.

### 3. RELIABILITY PARAMETERS

A reliability parameter in Risk Spectrum is basically a numerical value, optionally including an uncertainty distribution. The parameter name can be regarded as a variable to be used in the mathematical formulas for reliability calculations. When the formula is to be calculated, the variable name is replaced by the numerical value stored in the parameter record.

The value of the parameter is specified by a point estimate (mean) value and, optionally, an uncertainty distribution.

#### 3.1. Parameter Types

There are 8 different types of parameters in the reliability models of Risk Spectrum. The parameter types are listed in the following table which also gives the numerical limitations for each parameter.

There are 8 different types of parameters in Risk Spectrum models. Table II. gives the list of parameter types.

<table>
<thead>
<tr>
<th>Parameter type</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>( q )</td>
</tr>
<tr>
<td>Failure rate, frequency</td>
<td>( r, f )</td>
</tr>
<tr>
<td>Repair time (MTTR)</td>
<td>( TR )</td>
</tr>
<tr>
<td>Test interval</td>
<td>( TI )</td>
</tr>
<tr>
<td>Time to first test</td>
<td>( TF )</td>
</tr>
<tr>
<td>Mission time</td>
<td>( TM )</td>
</tr>
<tr>
<td>CCF</td>
<td>( * )</td>
</tr>
</tbody>
</table>

Table II. – Parameters in reliability models

#### 3.2. Uncertainty Analysis

The uncertainty analysis calculates a probability distribution for the to event result (as opposed to the point value calculated in MCS-analysis). The uncertainty analysis is based on Monte Carlo simulation.

The following steps are performed in the uncertainty analysis for a top event:

- The uncertainty analysis specification is read from the Analysis Case record.
The module-MCS are read from the binary result file (with extension .RSL).
The data for basic events and parameters are read from the project data base.
The Monte Carlo simulation process is made by calculating the top event unavailability NSIM (= number of simulations in specification) times, each time with a Monte Carlo simulated set of reliability parameters.
The resulting uncertainty distribution is printed to the result file.

3.3. Importance and Sensitivity Analysis

The importance analysis function can calculate importance and a special type of sensitivity measure for:
- Individual basic events
- Groups of basic events characterized by the same attribute
- Groups of basic events that belong to the same component
- Groups of basic events that belong to the same system
- Groups of basic events defined in the special basic event groups provided in Risk Spectrum
- CCF groups
- Individual parameters.

For each of these categories of importance calculations, three different importance measures are calculated:
- Fractional contribution
- Fussell-Vesely importance (only for basic events and CCF events)
- Risk decrease factor (also known as risk reduction worth)
- Risk increase factor (also known as risk achievement worth)

All calculations for basic events, CCF events, modules, and MCS sets are made according to the description in the section "MCS Quantification" of the chapter "Minimal Cut Set Analysis". The MCS quantification is always made using min cut upper bound approximation.
The calculation of unavailability for basic events is made differently depending on calculation type selected in the MCS-analysis specification:

3.4. Time-Dependent Analysis

The time-dependent analysis calculates a probability distribution for the top event result.

The following steps are performed in the time-dependent analysis for a top event:
- The time-dependent analysis specification is read from the top event record.

4. DRAIN SUPPLY AVAILABILITY IN STATIONS WITH SINGLE AND AUXILIARY BUSBARS

Availability of single busbars can be increased by installing auxiliary busbars into the switchyard with single busbars. In so doing, the spare switch in the drain is activated if the switch failure occurs. Drain scheme with single and auxiliary busbars is presented in Figure 1.

![Figure 1: Drain scheme with single and auxiliary busbars](image)

Results and diagrams of cross-section minimal analysis (MSC) are given in Table III and in Figure 2. As assumed, the transformer has major influence regarding unavailability in such a station, then there are switches, busbars and finally disconnectors. MCS analysis without transformer's influence did not bring about significant changes in components influence order on the total availability, it only pointed out different values of component influence.
5. PARALLEL PRESENTATION OF DIFFERENT MODEL AVAILABILITY

Figure 3: Availability and reliability of single busbars with auxiliary ones.

Plan construction - Description -
Availability, Reliability, Component number
A1_S+TR Single busbars with transformer 0.99761, 0.736, 7
AA1_S+RS3=TR-1 Single with longitudinal disconnector and TR 0.99826, 0.847, 8
AA1_S+2_ODV=RS3=TR-1 Single with two drains, RS3 and TR 0.99826, 0.847, 11
AA1_S+2_ODV=2RS=TR-1 Single with 2 drains, 2 disconnectors and transformer 0.99826, 0.847, 12
AA1_S+UZD_RS=2TR-1 Single with 2 drains, longitudinal disconnector and 2 transformers 1.0000, 0.99943, 20

Table IV: Single busbars comparison

Plan construction - Description -
Availability, Reliability, Component number
A2_S+TR Double with transformer 0.99809, 0.782, 10
A2_S+SP_POLJE=TR-1 Double with junction field and TR 0.99809, 0.782, 13
A2_S+POM=TR-1 Double with auxiliary and TR 0.99867, 0.877, 15
A2_S+SP_POLJE2+TR-1 Double with junction field and TR − parallel 0.99917, 0.9571, 18

Table V: Double busbars comparison results

6. CONCLUSIONS

Risk Spectrum programme package was used for the analysis of failure tree availability method. Risk Spectrum is made by the Sweden company RELCON AB, which is considered to be one of the leading consultative companies in the field of risk availability and reliability analysis in the world.

The paper deals with drain availability analysis with single and auxiliary busbars. Results of simpler
plants, like those with single and double busbars, showed substantial influence of series connected components (transformer, switch, disconnector). When more complex plants are considered (with auxiliary busbars, more drains, junction fields, triple busbars) a problem was encountered, i.e. modeling of the system itself due to high redundancy in the system. Therefore, teams of engineers will be required when larger system are to be installed and analyzed. Parallel analysis results of different plants are very important when plants are planned/installed. They are also important when the availability and safety in existing plants are increased.

The analysis of minimal cross sections (MCS) show critical points in plants and it also point out components which require special attention during system analysis. Importance and sensitivity analysis point out components which are responsible for total unavailability of the plant and which are the components whose changing has the smallest and/or biggest influence on the decrease or increase of the availability of the whole plant. Time dependent analysis shows time dependent availability and what is even more important, it shows failure intensity.

All these analysis will be a useful guide to the engineer in choosing the best and optimal solution for building a switchyard station. Of course, number of components and economical aspects of each plant should be taken into consideration.

References


